Physical Property of Ternary Blend Concrete Using Finely-Ground Fly Ash and Finely-Ground Granulated Blast Furnace Slag

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ABSTRACT

This study analyzes the physical properties of a ternary blend concrete in which finely-ground fly ash and finely-ground granulated blast furnace slag are added. The results of this study are used to evaluate the feasibility of using the ternary blend as a material for bridge deck overlay. The concrete mixtures in this study consist of: (i) a replacement of 0~20% finely-ground fly ash and (ii) a replacement of 0~20% finely-ground granulated blast furnace slag. In all, four tests were conducted on the two mixtures: the slump test, the air content test, the compressive strength test, and the chloride penetration resistance test.

The results show that Pozzolanic concrete has an increasing rate of compressive strength than plain concrete over time. In particular, the Pozzolanic concrete has 150% more compressive strength at 90 days than plain concrete. However, a binary blend concrete with a replacement of Pozzolanic material and a ternary blend concrete with replacements of two Pozzolanic materials—finely-ground fly ash and finely-ground granulated blast furnace slag—show only a slight difference in concrete compressive strength. The difference is that the Pozzolanic concrete has superior penetration resistance when compared to plain concrete. Also results show that the ternary blend concrete has a very low grade of penetration resistance. In fact the ternary blend concrete has better penetration resistance than binary blend concrete.

These results indicate that the ternary blend concrete has an advantage in durability. It is possible therefore to apply it to the material for bridge deck overlay where high performance concrete is required. Further experiments are needed to determine the proper replacement ratio for Pozzolanic materials. Further testing of the durability of the materials is also needed to follow up this study.

1. Introduction

A bridge deck slab generally consists of a structural concrete deck that is overlain by a pavement concrete bridge deck on top of it. The separate construction of the structural concrete deck from the pavement ensures that the structural member is not directly exposed to open air. It further minimizes the effect of environmental loads and maximizes the life span of the bridge deck slab by allowing for repetitive replacement of the pavement portion of the slab.

The process of separate construction requires that the material for bridge deck overlay have adequate strength and penetration resistance to withstand the traffic and environmental loads.

Maintenance costs may be minimized by lengthening of the replacement interval.

Recently it has been suggested that a high-performance pavement concrete be used for bridge deck slab construction. This blend consists of latex-modified concrete and silica fume modified concrete. It has been used because of its improved durability over plain concrete. However, these latex and silica fume, are expensive materials and therefore have low economic efficiency.

Thus, finely-ground fly ash (FGFA) and finely-ground granulated blast furnace slag (FGGBS) are suggested as substitute materials for silica fume. These two materials crushed into fine particles have high fineness which makes the Pozzolanic reaction faster and more highly activated.

Kefeng Tan and Xincheng Pu (1998) reported that a concrete mixture with a replacement of FGFA combined with FGGBS had a higher compressive strength than either replacement—FGFA or FGGBS—by itself. The study also showed that a concrete mixture with FGFA and FGGBS has similar compressive strength to a concrete mixture with silica fume. A study by Halit Yazici et al (2008) showed that the effectiveness of an increase in the amount of finely-ground fly ash and finely-ground granulated blast furnace while the amount of silica fume is decreased. This result suggests that both materials may act as proper substitute materials for the silica fume.

As a result of these findings and others, this study sets out to analyze the physical properties of a ternary blend concrete with FGFA and FGGBS. The results of this study will be used to evaluate the feasibility of applying this ternary blend as a material for bridge deck overlay.

2. Experimental Test Scheme

2.1 Outline

The concrete mixture in this study consists of a replacement of 0~20% finely-ground fly ash, a replacement of 0~20% finely-ground granulated blast furnace slag, and combination of each material. In all, four tests were conducted: the slump test, the air content test, the compressive strength test, and the chloride penetration resistance test.

2.2 Materials

(1) Portland cement and UFFA

Table 1 shows the properties of chemical components of FGFA, FGGBS and Portland cement.

Table 1. Chemical Components of FGFA, FGGBS and Cement

Type	Chemical Composition (%)						Fineness
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Blain Method (cm^2/g)
FGFA	58.3	22.3	7.2	3.1	1.1	0.3	6,258
FGGBS					5.63	1.11	6,530
Portland Cement	51.6	24.1	6.53	8.08	0.97	0.63	3,273

(2) Aggregate

The fine aggregate used in this study is a wash aggregate of sea sand from Haeju of North Korea and sea sand from the Uechung Island of South Korea. The crushed rock of 13mm was used as a coarse aggregate. Figure 1 shows the gradation of fine aggregate and coarse aggregate.

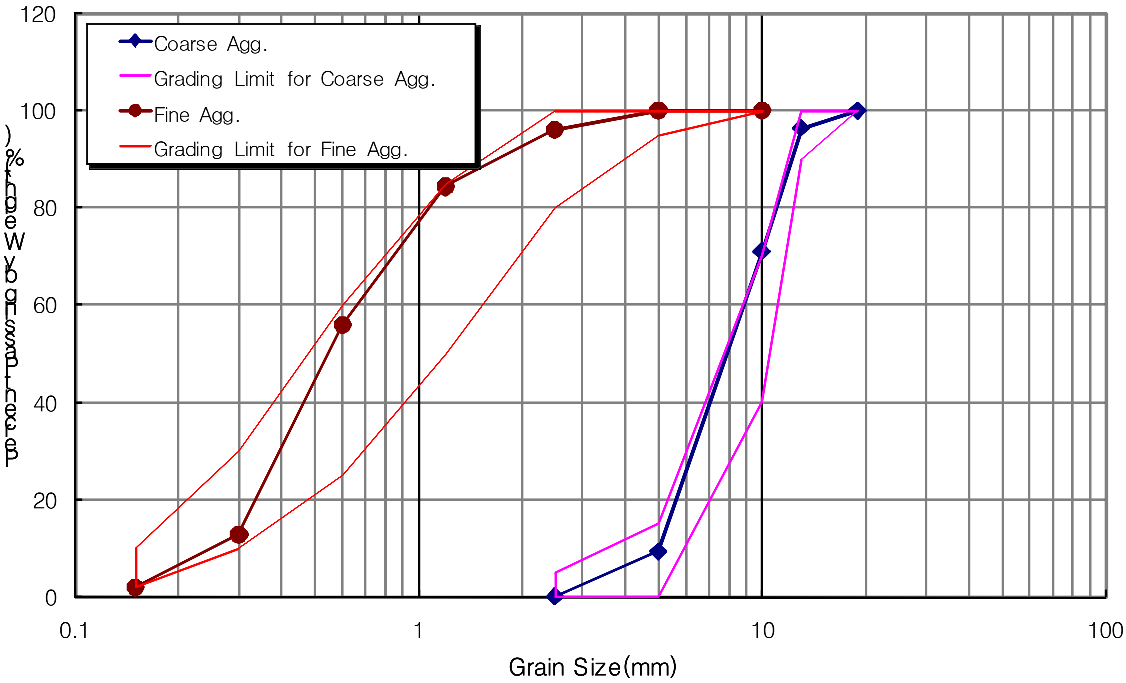

Figure 1. Gradation of Fine and Coarse Aggregate

<u>2.3 Test Methods</u>

(1) *Slump Test / Air Content Test*

The slump test is one of the measurement methods for the fluidity of fresh cement. For the purposes of this study, a sample was taken in accordance with KS F 2401 (a method for taking samples of fresh cement) and the test was carried out according to KS F 2402 (a slump test method of concrete).

The air content test, which affects the compressive strength and durability of cement, was performed using the Washington Type Concrete Air Meter based on KS F 2421 (an air content test method based on the pressure method of fresh concrete).

The air content test was made two times for each mixture in order to ensure better accuracy. The average of the two values was used to get the results.

(2) *Compressive Strength Test*

A specimen was made as stipulated in the standard-size specimen [KS F 2403 (a method used at a lab for manufacturing and curing a specimen used in testing of compression, flexural and splitting tensile strength)]. The compressive strength test was then performed in accordance with KS F 2405 (test method for concrete compressive strength test) at 7 days, 28 days, 56 days, and 90 days. The average compressive strength was calculated using three samples for each variable. Instron 8150 was used for the compressive strength test.

(3) *Rapid Chloride Penetration Resistance Test*

The rapid chloride penetration resistance test makes it possible to figure out the penetration resistance of concrete in a relatively short period of time compared with the general permeability test. Figure 2 shows how to perform the test.

Figure 2. Rapid Chloride Penetration Resistance Test

The rapid chloride penetration resistance test was carried out at 28 days, 56 days, and 90 days in accordance with KS F 2711. The average charge passed was calculated using two samples for each variable.

2.4 *Mixture Ratio*

Table 2 shows the mixture proportions. The concrete mixture in the study consists of (i) a replacement of 10~20% FGFA combined with a replacement of 10~20% FGGBS, (ii) a replacement of 0~20% FGFA, and (iii) a replacement of 0~20% FGGBS. In this study, the water-cement ratio is 45%, the percentage of fine aggregate is 50%, and the high-range water reducer is 0.5%. Generally since fly ash and slag lead to a decline in the air content of the concrete mixture, the amount of air-entrainer (AE) varies 1~4% according to the replacement ratio of Pozzolanic materials.

Table 2. Mixture Proportions

Name	FGFA replacement ratio (%)	FGGBS replacement ratio (%)	G_{max} (mm)	W/C (%)	S/a (%)	Unit Weight (kg/m³)						HRWR* (%) *against the weight of Binder	AE** (%) **against the weight of HRWR
						W	Binder			S	G		
							C	FGFA	FGGBS				
F0S0	0	0	13	45	50	175.5	390.0	0	0	855.7	881.9	0.5	1
F10S0	10	0				175.5	351.0	39	0	850.3	876.3	0.5	1.5
F20S0	20	0				175.5	312.0	78	0	844.9	870.8	0.5	2
F0S10	0	10				175.5	351.0	0	39	854.2	881.9	0.5	1.5
F0S20	0	20				175.5	312.0	0	78	852.8	882.0	0.5	2
F10S10	10	10				175.5	312.0	39	39	848.8	874.8	0.5	2
F10S20	10	20				175.5	273.0	39	78	847.3	873.3	0.5	3
F20S10	20	10				175.5	273.0	79	39	843.4	869.3	0.5	3
F20S20	20	20				175.5	234.0	78	78	842.0	867.8	0.5	4

3. Experimental Results

3.1 *Results of the Slump Test and Air Content Test*

The results of the slump test are shown in the Figure 3. The results show that as the replacement ratio of Pozzolanic materials increases, the overall initial slump tends to increase. In particular, the finely-ground granulated blast furnace slag has a larger improvement in workability than finely-ground fly ash. This study used Pozzolanic materials which were crushed into fine particles that were square in shape. These show less improvement in workability than the particles that are round in shape.

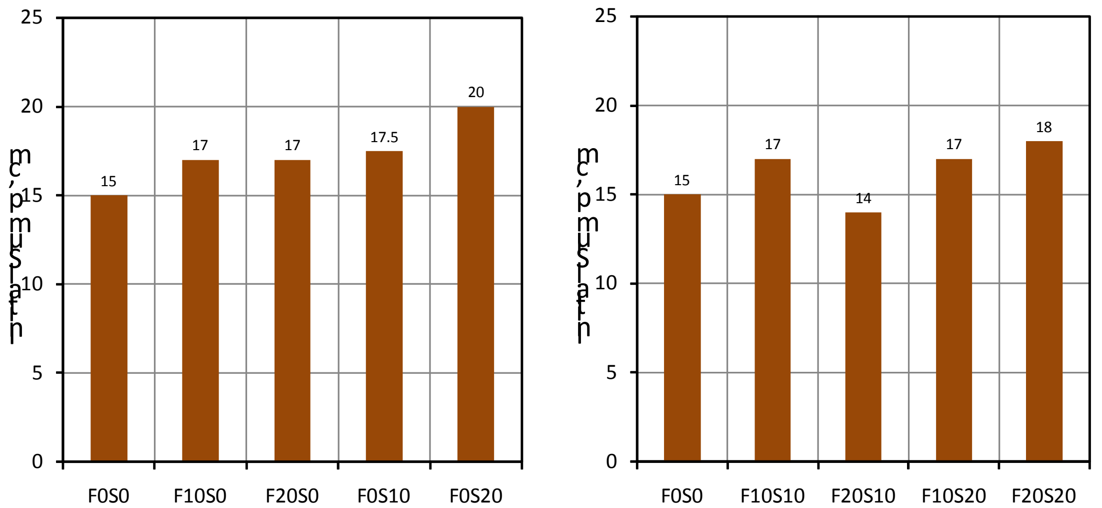

Figure 3. Results of Slump Test

Figure 4 shows the results of the air content test. The amount of air-entrainer varies in accordance with the replacement ratio of Pozzolanic materials in this study. An extra 0.5% of air-entrainer was added for each 10% replacement ratio of Pozzolanic materials. This variation in the amount of air-entrainer is to maintain consistent air content because the concentration of air-entrainer in the cement paste decreases as the air-entrainer is absorbed into the Pozzolanic materials. As figure 4 shows, all mixtures have the proper air content. The air content showed big differences among the mixtures. In particular, the mixture with a replacement of FGFA showed less air content than other mixtures while a mixture with a FGGBS had similar or slightly more air content than other mixtures. These results indicate the FGFA has more of an effect on the reduction of concentration of air-entrainer than FGGBS.

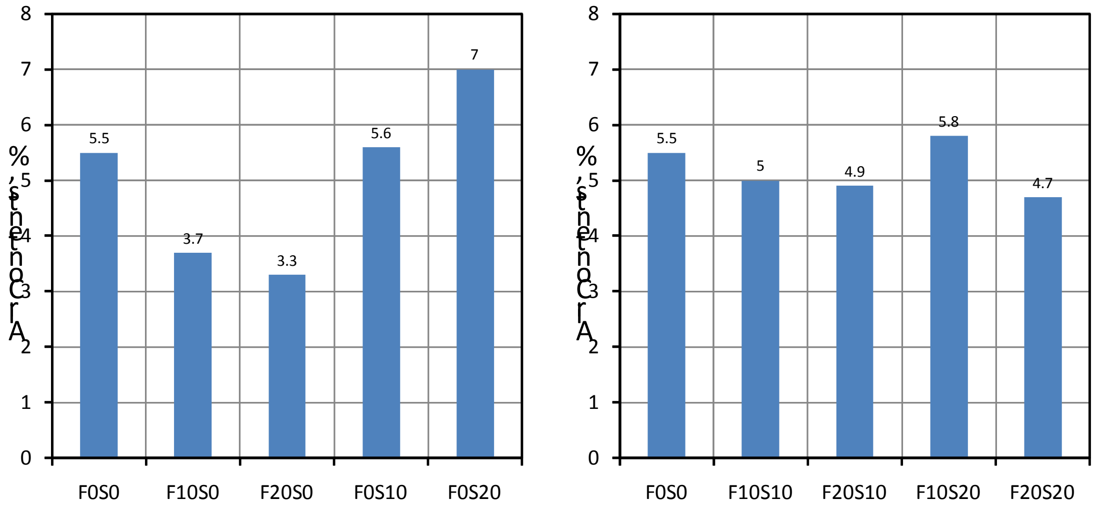

Figure 4. Results of Air Content Test

3.2 *Results of the Compressive Strength Test*

Figure 5 shows the results of the compressive strength test on concrete mixtures for each day. At 7 days, the compressive strengths of each mixture showed similar values, but after 28 days the Pozzolanic concrete showed a higher increasing rate than plain concrete. After 90 days, the compressive strength of Pozzolanic concrete showed compressive strength 1.5 times higher than plain concrete. However, a binary blend concrete with a replacement of a Pozzolanic material and a ternary blend concrete with replacements of two Pozzolanic materials show only a slight difference in the compressive strength.

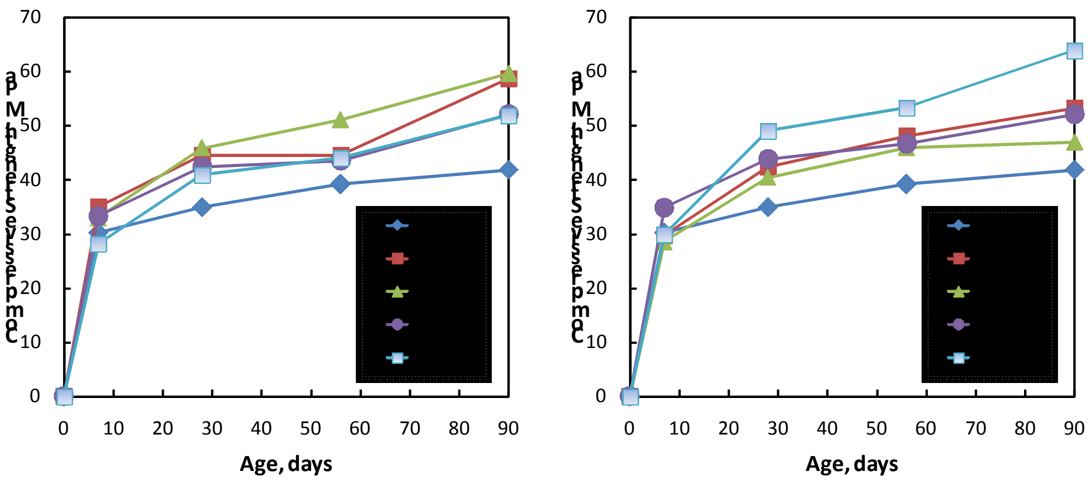

Figure 5. Results of the Compressive Strength Test

Figure 6 compares the effect of each Pozzolanic material. Where the amount of finely-ground granulated blast furnace slag was fixed at 0%, and the amount of finely-ground fly ash increased from 0% to 20%, the compressive strength of concrete increased 31%, 30%, and 42% at days 28, 56, and 90 respectively. Where the amount of finely-ground fly ash was fixed at 0%, and the amount of finely-ground granulated blast furnace slag increased from 0% to 20%, the compressive strength of concrete increased 17%, 13%, and 24% at days 28, 56, and 90 respectively.

Where the amount of finely-ground granulated blast furnace slag fixed at 10%, and the amount of finely-ground fly ash increased from 0% to 20%, the compressive strength of concrete showed 0%, 10%, and 0% increase in strength or same as at days 28, 56, and 90 respectively. However, it still tended to increase only slightly. As for the case where the amount of finely-ground fly ash was set at 10%, and the amount of finely-ground granulated blast furnace slag increased from 0% to 20%, the compressive strength of concrete increased 3% at day 56, but decreased 9% and 20% at days 28 and 90 respectively.

Where the amount of finely-ground granulated blast furnace slag was fixed at 20%, and the amount of finely-ground fly ash increased from 0% to 20%, the compressive strength of concrete increased 19%, 20%, and 23% at days 28, 56, and 90 respectively. As for the case where the amount of finely-ground fly ash was set at 20%, and the amount of finely-ground granulated blast furnace slag increased from 0% to 20%, the compressive strength of concrete increased 6%, 4%, and 7% at days 28, 56, and 90 respectively.

From these test results, it is evident that finely-ground fly ash has more of an effect on improvement of concrete strength than finely-ground granulated blast furnace slag. This suggests that an increasing amount of finely-ground fly ash rather than finely-ground granulated blast furnace slag in the ternary blend concrete is more beneficial in terms of concrete strength.

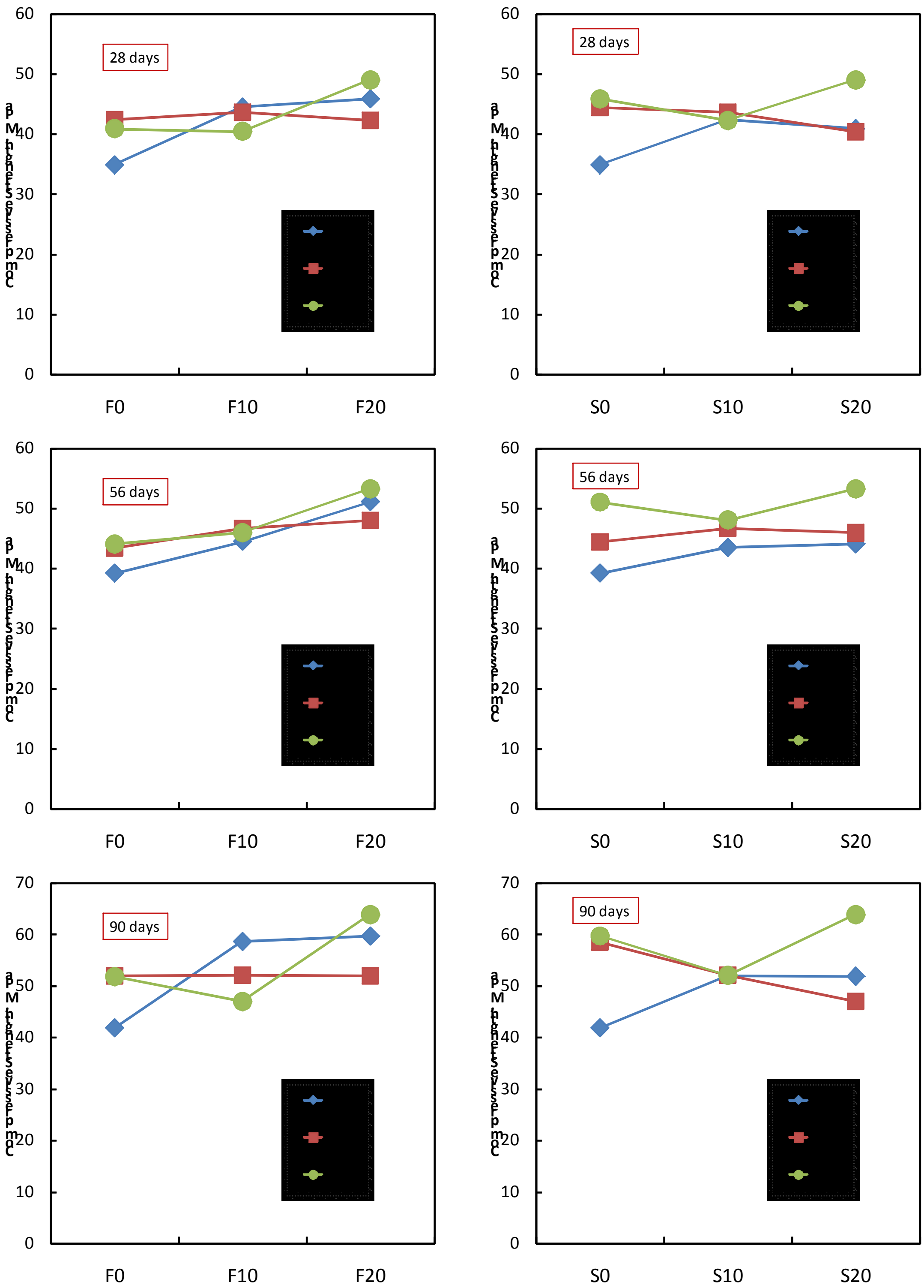

Figure 6. Comparison of Strength Effect in the amount of Pozzolanic Material

3.3 *Results of Rapid Chloride Penetration Resistance Test*

Figure 7 shows the results of the rapid chloride penetration resistance test. It shows that the passed charge of Pozzolanic concrete is less than plain concrete. This is evidence that the Pozzolanic concrete has superior penetration resistance compared to plain concrete. Additionally, the ternary blend concrete has a very low grade of penetration resistance. In fact, it has been shown to have better penetration resistance than binary blend concrete.

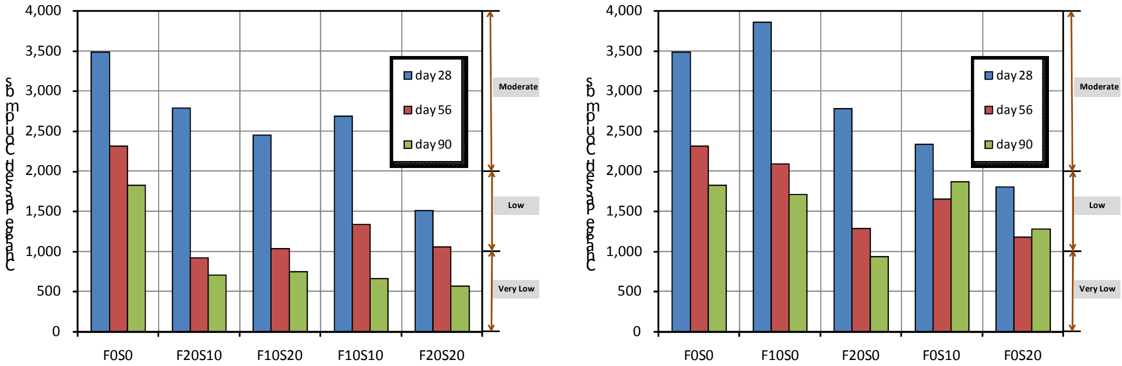

Figure 7. Results of Rapid Chloride Penetration Resistance Test

Figure 8 compares the effect of each Pozzolanic material. Where the amount of finely-ground granulated blast furnace slag is fixed at 0%, and the amount of finely-ground fly ash increased from 0% to 20%, the passed charge of the concrete decreased 20%, 44%, and 49% at days 28, 56, and 90 respectively. Additionally where the amount of finely-ground fly ash was set at 0%, and the amount of finely-ground granulated blast furnace slag increased from 0% to 20%, the passed charge of the concrete decreased 48%, 49%, and 30% at days 28, 56, and 90 respectively.

Where the amount of finely-ground granulated blast furnace slag was fixed at 10%, and the amount of finely-ground fly ash increased from 0% to 20%, the passed charge of the concrete increased 19% at day 28. However, the passed charge of the concrete sharply decreased by 45% at day 56 and by 62% at day 90. In the case where the amount of finely-ground fly ash was set at 10%, and the amount of finely-ground granulated blast furnace slag increased from 0% to 20%, the passed charge of the concrete decreased 37%, 57%, and 56% at days 28, 56, and 90 respectively.

Where the amount of finely-ground granulated blast furnace slag was fixed at 20%, and the amount of finely-ground fly ash increased from 0% to 20%, the passed charge of the concrete increased 16%, 11%, and 55% at days 28, 56, and 90 respectively. In the case where the amount of finely-ground fly ash was set at 20%, and the amount of finely-ground granulated blast furnace slag increased from 0% to 20%, the passed charge of the concrete increased 46%, 18%, and 39% at days 28, 56, and 90 respectively.

The results of these tests suggest the following: the Pozzolanic reaction was not fully activated for the finely-ground fly ash until the 28th day; between day 28 and day 90, the penetration resistance of the concrete was significantly improved due to a highly activated Pozzolanic reaction. The tests also suggest that the Pozzolanic reaction was activated immediately for the finely-ground granulated blast furnace slag. From this fact, it was found that the penetration resistance of concrete was significantly reduced at day 28 for concrete with FGGBS. The reduction rate of penetration resistance decreased over time.

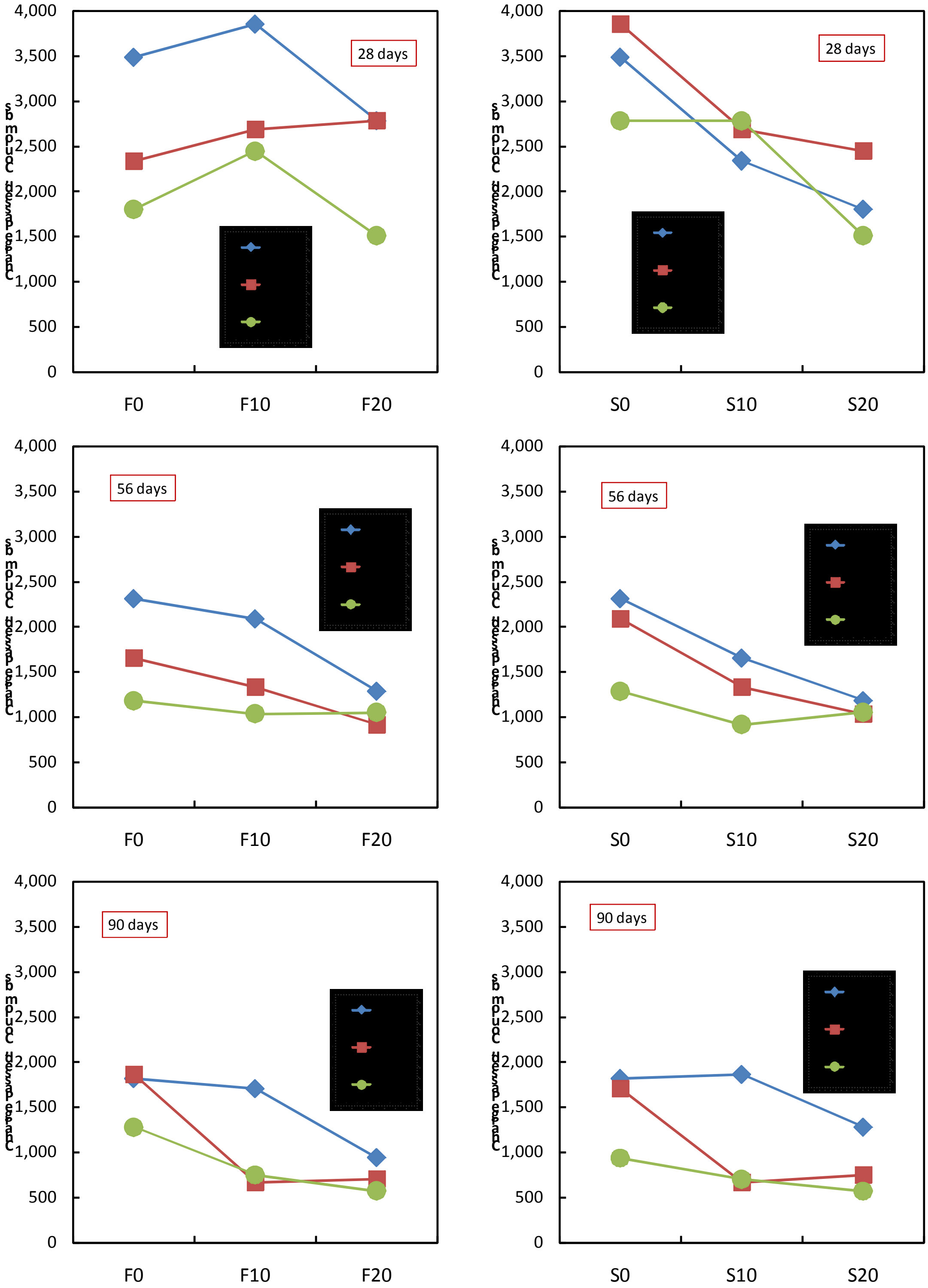

Figure 8. Comparison of Penetration Effect in the amount of Pozzolanic Material

4. Conclusion

In this study, the physical properties of a ternary blend concrete with finely-ground fly ash and finely-ground granulated blast furnace slag were analyzed to evaluate the feasibility of applying the ternary blend concrete as a material for bridge deck overlay.

From the results gathered from this study, the following conclusions have been drawn:

1. As the replacement ratio of Pozzolanic materials increases, the overall initial slump tends to increase. Between the two studied Pozzolanic materials, the finely-ground granulated blast furnace slag produces a larger improvement in workability than the finely-ground fly ash.

2. Where Pozzolanic materials are used, the proper air content has to be secured by increasing the amount of air-entrainer after considering the affected decrease of concentration of air-entrainer. From the test results in this study, all mixtures have proper air contents. Between the two studied Pozzolanic materials, the finely-ground fly ash has more of an effect on reducing the concentration of air-entrainer than finely-ground granulated blast furnace slag. Therefore the additional amount of air-entrainer needs to be applied differently based on the replacement ratio of Pozzolanic materials and the different properties of each.

3. Over time, the compressive strength of Pozzolanic concrete showed a higher increasing rate than plain concrete. In particular, at 90 days the compressive strength of Pozzolanic concrete was maximized to 1.5 times the strength of plain concrete. Even though a binary blend concrete with a replacement of a Pozzolanic material and a ternary blend concrete with replacements of two Pozzolanic materials show only a slight difference in concrete compressive strength, finely-ground fly ash has more of an effect on improved concrete strength than finely-ground granulated blast furnace slag. This suggests that by increasing the amount of finely-ground fly ash in the ternary blend concrete, the more of a beneficial effect on concrete strength the blend will have.

4. From the results of rapid chloride penetration resistance test, the Pozzolanic concrete has superior penetration resistance compared to plain concrete. In particular, the ternary blend concrete showing very low grade has a better penetration resistance than the binary blend concrete does.

5. The results of the rapid chloride penetration resistance test indicate that the ternary blend concrete has an advantage in durability and that it is possible to apply to the material for bridge deck overlay where high performance concrete is required.

It is recommended that the results of this study be supplemented with further experiments that seek to determine the proper replacement ratio for the Pozzolanic materials and to verify the suggested ratio through a durability test.

Reference

1. Kefeng Tan and Xincheng Pu (1998), Strengthening Effects of Finely Ground Fly Ash, Granulated Blast Furnace Slag and their Combination," Cement and Concrete Research, Vol.28, No.12, pp.1819-1825.
2. Halit Yazici, Huseyin Yigiter, Anil S. Karabulut, Bulent Baradan (2008), "Utilization of Fly Ash Ground Granulated Blast Furnace Slag as an Alternative Silica Source in Reactive Powder Concrete", Fuel 87, 2401-2407.